Shell-model interpretation of high-spin states in ^{134}I

L. Coraggio[1], A. Covello[1,2], A. Gargano[1], and N. Itaco[1,2]

[1]*Istituto Nazionale di Fisica Nucleare, Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy*

[2]*Dipartimento di Scienze Fisiche, Università di Napoli Federico II,*
Complesso Universitario di Monte S. Angelo, I-80126 Napoli, Italy

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New experimental information has been recently obtained on the odd-odd nucleus ^{134}I. We interpret the five observed excited states up to the energy of ∼3 MeV on the basis of a realistic shell-model calculation, and make spin-parity assignments accordingly. A very good agreement is found between the experimental and calculated energies.

In a recent paper [1], excited levels up to an energy of about 3 MeV were identified for the first time in ^{134}I through the measurements of prompt γ rays from the spontaneous fission of ^{252}Cf. A five transition cascade was observed, but the measured angular correlations were not sufficient to assign spins and parities. In this connection, it may be mentioned that preliminary results were also reported in Ref. [2] on some new γ transitions in ^{134}I populated in the reaction ^{136}Xe + ^{208}Pb. It is the aim of the present paper to give a shell-model interpretation of the observed levels.

The study of nuclei in the vicinity of doubly magic ^{132}Sn is indeed a subject of great current experimental and theoretical interest. Experimental information on these nuclei, which have been long inaccessible to spectroscopic studies, is now becoming available offering the opportunity to test shell-model calculations in regions of shell closures off stability.

The odd-odd nucleus ^{134}I with three protons and one neutron hole away from ^{132}Sn represents an important source of information on the matrix elements of the proton-neutron hole interaction. Actually, the most appropriate system to study this interaction is ^{132}Sb with only one proton valence particle and one neutron valence hole. Experimental information on this nucleus was provided by the studies of Refs. [3–5] and there have also been various shell-model studies employing realistic effective interactions [6–8]. Both the calculations of Refs. [7] and [8] start from the CD-Bonn nucleon-nucleon (NN) potential and derive the effective proton-neutron interaction within the particle-hole formalism. In the former paper, however, the short-range repulsion of the NN potential is renormalized by means of the $V_{\text{low}-k}$ approach [9] while in [8] use is made of the traditional Brueckner G-matrix method.

The nucleus ^{134}I, with an additional pair of protons with respect to ^{132}Sb, may certainly contribute to improve our knowledge of the two-body effective interaction, since it offers the opportunity to investigate its effects when moving away from the one proton-one neutron hole system. This was also the motivation for extending, in Ref. [7], our shell model calculations to the nucleus ^{130}Sb with three neutron holes.

In our calculations we consider ^{132}Sn as a closed core and let the valence protons and neutron hole occupy the five levels $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, and $0h_{11/2}$ of the 50-82 shell. The single-particle and single-hole energies have been taken from the experimental spectra [10] of ^{133}Sb and ^{131}Sn, respectively. The only exception is the proton $\epsilon_{s_{1/2}}$ which has been taken from Ref. [11], since the corresponding single-particle level is still missing in the spectrum of ^{133}Sb. Our adopted values for the proton single-particle energies are (in MeV): $\epsilon_{g_{7/2}} = 0.0$, $\epsilon_{d_{5/2}} = 0.962$, $\epsilon_{d_{3/2}} = 2.439$, $\epsilon_{h_{11/2}} = 2.793$, and $\epsilon_{s_{1/2}} = 2.800$, and for the neutron single-hole energies: $\epsilon_{d_{3/2}}^{-1} = 0.0$, $\epsilon_{h_{11/2}}^{-1} = 0.065$, $\epsilon_{s_{1/2}}^{-1} = 0.332$, $\epsilon_{d_{5/2}}^{-1} = 1.655$, and $\epsilon_{g_{7/2}}^{-1} = 2.434$. Note that for the $h_{11/2}$ level we have taken the position suggested in Ref. [12].

As in our recent studies [13–16] in the ^{132}Sn region, we start from the CD-Bonn NN potential [17] and derive the $V_{\text{low}-k}$ with a value of the cutoff parameter $\Lambda = 2.2$ fm^{-1}. This low-momentum potential, with the addition of the Coulomb force for protons, is then used to derive the effective interaction V_{eff} within the framework of the $\hat{Q}$-box folded diagram expansion [9] including diagrams up to second order in $V_{\text{low}-k}$. The computation of these diagrams is performed within the harmonic-oscillator basis, using intermediate states composed of all possible hole states and particle states restricted to the five shells above the Fermi surface. This guarantees stability of the results when increasing the number of intermediate states. The oscillator parameter is $\hbar\omega = 7.88$ MeV.

As mentioned above, the effective proton-neutron interaction is derived directly in the particle-hole representation, while for the proton-proton interaction we use the particle-particle formalism. The shell-model calculations have been performed using the OXBASH computer code [18].

Let us now start to present our results by comparing in Table I the calculated low-energy spectrum of ^{134}I with the experimental one [19]. The levels shown in this table, which have all been identified in the ^{134}Te β decay, were also observed in the experiment of Ref. [1]. We see that the experimental energies are very well reproduced by theory, the largest discrepancy, 160 keV, occurring for the 8^- state. For the two positive-parity states at 0.181 and 0.210 MeV excitation energy our calculation speaks
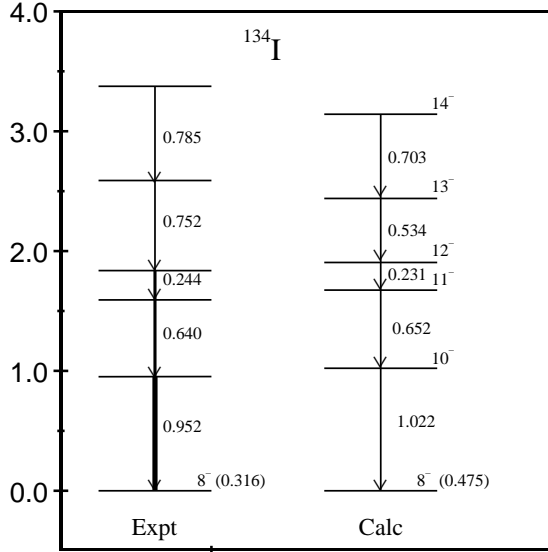
FIG. 1: The five-transition cascade observed in ^{134}I is compared with the calculated level scheme for negative-parity yrast states.

lowest-lying populated level does not lead to any theo-

TABLE I: Experimental and calculated energies (in keV) of the lowest lying states in ^{134}I. Wave-function components with a percentage $\geq 10\%$ are reported.

J^{π}_{Exp}	E_{Exp}	J^{π}_{Th}	E_{Th}	Configuration	Probability
$(4)^{+}$	0	4^{+}	0	$\pi(g_{7/2})^3\nu(d_{3/2})^{-1}$	78
$(5)^{+}$	44	3^{+}	51	$\pi(g_{7/2})^3\nu(d_{3/2})^{-1}$	77
$(3)^{+}$	79	5^{+}	122	$\pi(g_{7/2})^3\nu(d_{3/2})^{-1}$	81
$(2,3)^{+}$	181	2^{+}	158	$\pi(g_{7/2})^3\nu(d_{3/2})^{-1}$	78
$(2,3)^{+}$	210	3^{+}	312	$\pi(g_{7/2})^3\nu(s_{1/2})^{-1}$	60
				$\pi g_{7/2})^3\nu(d_{3/2})^{-1}$	24
$(8)^{-}$	316	8^{-}	475	$\pi(g_{7/2})^2\nu(h_{11/2})^{-1}$	75
				$\pi g_7/2(d_{3/2})^2\nu(h_{11/2})^{-1}$	12

TABLE II: Wave functions of negative-parity yrast states of ^{134}I (components ≥ 10 % are reported).

J^{π}	Component	Probability
10^{-}	$\pi(g_{7/2})^3\nu h_{11/2}^{-1}$	89
11^{-}	$\pi(g_{7/2})^2 d_{5/2}\nu h_{11/2}^{-1}$	92
12^{-}	$\pi(g_{7/2})^2 d_{5/2}\nu h_{11/2}^{-1}$	93
13^{-}	$\pi(g_{7/2})^3\nu h_{11/2}^{-1}$	66
	$\pi(g_{7/2})^2 d_{5/2}\nu h_{11/2}^{-1}$	32
14^{-}	$\pi(g_{7/2})^2 d_{5/2}\nu h_{11/2}^{-1}$	97

in favour of a $J = 2$ and 3 assignment, respectively.

As regards the wave functions, it turns out that the six considered states are dominated by a single configuration, as is shown by the percentages reported in Table I. It is interesting to note that these states may be viewed as the evolution of the six lowest-lying states in ^{132}Sb, the 8^- state being tentatively identified [19] with the 0.200 MeV level. As discussed in Ref. [7], the first four positive-parity states in ^{132}Sb are interpreted as members of the $\pi g_{7/2}\nu d_{3/2}^{-1}$ multiplet , while the 3^+ and 8^- states as the next to the highest J member of the $\pi g_{7/2}\nu s_{1/2}^{-1}$ and $\pi g_{7/2}\nu h_{11/2}^{-1}$ multiplets, respectively . The corresponding states in ^{134}I are dominated by the same proton-neutron hole configuration with the remaining two protons forming a zero-coupled pair. The main feature of the proton-neutron hole multiplets, namely the lowest position of the state with next to the highest J, seems to be preserved when adding two valence protons. We find, however, that in ^{134}I the members of a given multiplet lie in a smaller energy interval with respect to ^{132}Sb, as is experimentally confirmed in the case of the $\pi g_{7/2}\nu d_{3/2}^{-1}$ multiplet.

We now come to discuss the level scheme identified in Ref. [1], which is reported in Fig. 1 together with our shell-model interpretation. The observed γ cascade is composed of five transitions and was supposed to be built on the 0.316 MeV 8^- isomeric state. With this assumption, we find that the excitation energies of the experimental levels are well reproduced by the calculated yrast sequence shown in the figure. More quantitatively, the *rms* deviation between the calculated and experimental energies is about 100 keV.

We have verified that a different assumption for the

retical sequence that matches well with the experimental energies and is consistent with the observed transitions. It should be mentioned that at about 0.250 MeV below the 10^- state we find the yrast 9^- state, whose probability to be populated from the 10^- state is, however, about 30 times smaller than that relative to the 8^- state.

In Table II, we report the percentages of configurations larger than 10% for the $J^{\pi} = 10^-$, 11^-, 12^-, 13^-, and 14^- states. As in the case of the low-lying states (see Table I), each of these high-spin states is dominated by a single configuration. We see that in all five states the neutron hole occupies the $h_{11/2}$ level while the three protons are in the $(g_{7/2})^3$ or $(g_{7/2})^2 d_{5/2}$ configurations, with two protons coupled to $J \neq 0$. In particular, the two highest-lying levels arise from the maximum spin alignment of the corresponding configurations.

In summary, we have given here a shell-model description of ^{134}I, focusing attention on the energy levels recently identified from the spontaneous fission of ^{252}Cf [1]. We have assigned spins and parity to the new observed levels and obtained a very good agreement between experimental and calculated energies. Our shell-model effective interaction has been derived from the CD-Bonn NN potential without using any adjustable parameter, in line with our previous studies of other nuclei in the ^{132}Sn region. The accurate description obtained for all the investigated nuclei makes us confident in the results of the present work.

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